MULINO: Multi-sectoral, Integrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale

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Abstract: The goal of the MULINO project is the provision of a Decision Support System (DSS) to be used for the management of water resources at the catchment scale. The project aims to produce an operational tool that meets the needs of European water management authorities, by involving representatives from these authorities from five different EU countries in the DSS design. These potential MULINO-DSS users have specific contexts within which they must work. Their constraints include budgeting their working hours, deadlines for decisions, local legislation, European legislation, and new expectations for water management that oblige them to consult with the public and stakeholders during the decision making process. The development of the MULINO-DSS requires the integration of socio-economic and environmental modelling (distributed hydrological models in particular) with a geographic information system (GIS) and capabilities for muli-criteria analysis. The policy background is described by the EU Water Framework Directive of 23 October 2000. The primary objective of the Directive is to achieve 'good ecological status' for European water resources by the year 2015. The task of water managers is to promote the sustainable use of water resources – use which meets the needs of the present without compromising the ability of future generations to meet their own needs. An operational DSS that offers effective support for sustainable resource management has the dual task of modelling not only the environmental dynamics that condition the quantity and quality of supply, but also of modelling the dynamic social system in which resource use decisions must be taken. The relationship between human activities and the state of water resources is important as are the social conditions that have an effect on the decision making process itself, posing limits to decision makers. A primary challenge for the project is to produce a tool that is capable of modelling the dynamic system that conditions the water resources in a given catchment, and that also has a user interface that allows a step by step approach to evaluating the sustainability of water use options in a way that supports decision making.

Keywords: Water resources; Sustainable use; DSS; Catchment; Modelling

1. INTRODUCTION

The approach to water and waste water management is shifting in response to the task of balancing demand and availability, and water is being managed with a more business-like approach. In Europe there is still great variety in water management practices and an attempt to harmonise policies throughout the Union has resulted in the Water Framework Directive – WFD [EC, 2000] which focuses on catchment level management [EEA, 2000]. A significant obstacle to operational water managers is the large quantity of information requiring a high level understanding of a system whose elements have interactive relationships and of which the human population is an integral part. Basic principles of the WFD such as 'sustainable water use', 'good ecological status', 'integrated planning' and 'public participation' [EC, 2000] imply a change in the decision making process, and place a new focus on social systems which should be considered in relationship to environmental systems. Underlying the approach of the WFD is the concept that "water is not a commercial product like any other, but rather, a heritage which must be protected, defended and treated as such". The Directive recommends a 'polluter pays' approach and using pricing as a management tool. Through water pricing managers are expected to achieve "full cost recovery" for the provision of water services and to give incentives for users to use water resources efficiently.

The project entitled "MULINO", Multi-sectoral, integrated and operational decision support system for the sustainable use of water resources at the catchment scale, was funded by the European Commission under the 5th framework programme for Energy, Environment and Sustainable Development. It is one of a group of research projects that aim to contribute to the Programme's Key Action 1: "Sustainable Management and Quality of Water".

The Decision Support System being developed by the MULINO consortium aims at addressing these developments in natural resource management through the practical application of a decision tool. The project team is made up not only of specialists in hydrologic modelling, but includes software developers, economists, geographers, sociologists, agronomists and GIS specialists. The Fondazione ENI Enrico Matteri in Venice, Italy has the role of coordinating partner. The other partners that make up the consortium are : Centro de Investigação da Universidade Atlântica, Portugal; Departments of Geography and Geology of the Université Catholique de Louvain, Belgium; Silsoe Research Institute, United Kingdom; Agricultural and Regional Systems Unit, Space Applications Institute, Joint Research Centre, Ispra; Centre for Advanced Studies, Research and development in Sardinia; Research Institute of Soil Science and Agrochemistry of Bucharest, Romania; and Institute of Water and Environment, Cranfield University, United Kingdom. This inter-disciplinary team is working closely with water authorities from five countries in order to integrate environmental knowledge and management experience specific to study sites. The decision support needs expressed by these five user groups are considered to be priority input for defining the way in which the DSS is developed.

This paper presents MULINO at the end of its first semester, when the theoretical ideas developed for the project proposal have passed the first tests through discussions within the research consortium, together with the DSS end users identified so far. The decision support tool which will be released at the end of the project, through the development of three subsequent versions will have hydrologic modelling routines playing a primary role for supporting decisions on the basis of simulated alternative scenarios and possible solutions. The following text seeks to focus on broader theoretical and applicative contexts which define the context in which the implementation of models should be realised and reports on the preliminary developments achieved for the primary fields of study in MULINO's first phase.

2. THE NEW EU POLICY FRAMEWORK

Despite the marked diversity in MULINO's case studies, the European Water Framework Directive acts as a common denominator. EU member states are obliged to develop River Basin Plans according to the Directive's stipulations and have them operational by 2009. The Directive itself should be transposed into national legislation by 2003.

The remarkably innovative contents of this new Directive, designed for the sustainable management of water resources, must guide the development of the MULINO DSS if it is to be truly useful within the legislative framework for European natural resource management in the coming decade.

The DSS must be operational in the context of the project's case studies, which are defined at scales generally smaller than the territorial units, or River Basin Districts, that are the object of the WFD. The goal of the project is not to develop a tool for managing the WFD river basin plans, but nonetheless, experimentation with applying the DSS to larger territories is planned to trial the system for its potential use as support for the implementation of this new legislation.

Presenting the WFD perspective to an operational water manager should provide an additional assessment process to evaluate a given planning choice in terms of the objectives and obligations described in the Directive.

This scenario component should also guide the DSS user to explore the innovative management processes that are recommended and to develop strategies appropriate to actual socio-economic contexts. The EU Water Framework Directive is not only a response to the condition of Europe's water resources, but also a response to the socio-economic characteristics of the European Community. This new piece of legislation documents contemporary thought in the evolution of European political history.

Several trends have marked the development of the WFD and are be considered by Kaika [2001] as important factors that form its political background. Firstly, the privatization of the water sector in many EU countries has changed pricing systems and institutional structures for the management of public water supplies. Secondly, the internationalization of markets has led to changes in the scale of economic activities, and as a result the intensity of water use in some sectors. And thirdly, an ideological shift from a focus on 'government' towards new concepts about 'governance' has led to a re-examination of political processes and in some cases a redistribution of power between local and global approaches and within the structure of national governments.

These trends have brought about the emergence of new actors that now play a role in water resource management. EU Member States have approached management challenges in different ways. Two broad models have been identified by Mostert [1999]. He writes about the "authority model" in which authorities that are organized on the basis of hydrological boundaries and have independent financing and decision-making powers. In this case water management is a separate policy sector. The second model is called the "commission model" in which water management is considered within a broader portfolio of environmental management by a regular government body. In this case, river-basin commissions are often created to deal with the trans-boundary issues that arise from looking at hydrological boundaries to define water management strategies. Increasing concerns about the state of the natural environment, and dissatisfaction with the results of national governments' water and land use policies has strengthened the position of non-governmental organizations (NGOs).

Integrated management and public participation are new approaches that have been adopted in the Directive in connection with achieving sustainable water use. Therefore, decision support needs to identify and implement ways to include groups of stakeholders in the decision making process. The MULINO project will consider those problems, through actions targeted at the establishment of so-called "local networks" of stakeholders aimed at facilitating the exchange of information among people interested in the management of water resources. Nevertheless, for what concerns the development of the DSS tool group decision making processes will not be considered and the user interface will be designed for a single user identified in the local water management authority.

3. THE DSS STRUCTURE

The Driving force – Pressure – State – Impact – Response framework (DPSIR), proposed and used by the European Environment Agency (EEA), EUROSTAT and many other EU institutions and research projects was adopted to illustrate connections between the environment and human activities within the catchments. The basic structure of the framework is shown in Figure 1.

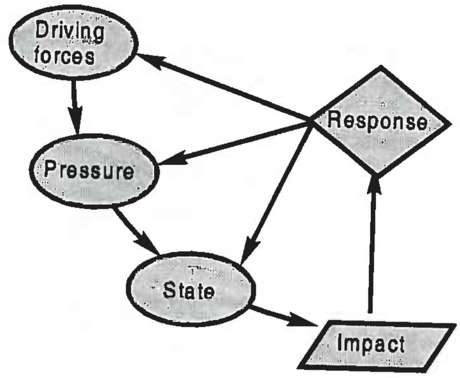

Figure 1. An overview of the DPSIR framework.

One of the first problems faced by the research team was to define the basic organisational structure of the tool, upon which to order the decision making steps. It is expected that, thanks to its flexibility, the DPSIR framework could be applied to a broad range of decision contexts, whilst being capable of managing enough detail to arrive at examining specific situations.

The DPSIR framework aims at analysing the cause-effect relationship between interacting components of complex social, economic and environmental systems and at organising the information flows in different systems of human activity [Woodhouse, 2000]. The framework was originally developed for social case studies and then broadly applied to environmental and sustainable development, describing and organising information expressed in the form of indicators.

Taking on this framework as a structure for the decision making process is supportive for making a shift towards sustainable resource use because it presents the resource use problem as including social, economic, and environmental aspects. This systemic presentation helps the decision maker to consider the immediate problem in the context of differing time frames by systematically looking at cause-effect relationships with varying proximity to the impact. Figure 2 illustrates how the framework takes on meaning in the context of water resource management.

In Figure 2 an example from the agricultural sector has been selected to show how the DPSIR chain may be constructed in practice. Irrigation is a main **driving force** affecting the water cycle..

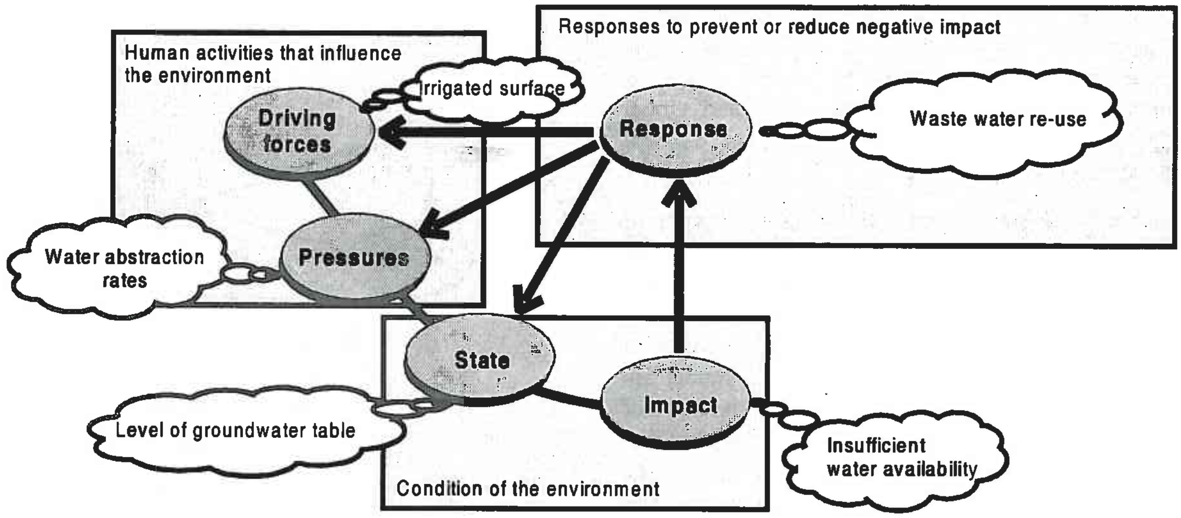

Figure 2. Water use in agriculture seen through the DPSIR framework.

The total area under irrigation is considered to estimate **pressures** on the water resource. In this example the water used for irrigation derives from groundwater abstraction. The **state** of water resources can then be assessed in terms of quantity. The water tablė level gives information about the condition of the groundwater resources, which can be monitored to evaluate changes in stock. The **impact** is a decrease of water availability which is related to the relationship between abstraction and supply. The assessment of this four-step chain provides information for setting targets for future policies and defining measures in order to reach them. The **response** in this example, consists in providing mechanisms for water treatment plants allowing waste water re-use for irrigation, thus reducing the Pressure of water abstraction. Responses may also consist in regulating or financial instruments.

DPSIR describes a cycle, providing a conceptual model that can give the DSS user a high-level view of the problem. This means that it structures the user's thinking, helping to develop a good understanding of the dynamics of the system within which decision making should occur. The DPSIR framework is thought to be particularly useful to the MULINO project also because it provides both a uniform structure through which to approach the case studies, which vary greatly, and an underlying design for the MULINO DSS software.

4. DSS AND HYDROLOGIC MODELS

Three releases of the MULINO-DSS prototype have been planned. The first prototype will serve to present and test the bare bones of the software and to involve DSS end users in the development of the user interface. The confirmation of the DSS structure will lead to subsequent releases of more evolved prototypes with greater integration of hydrologic models, and with the capacity for an evaluation of decisions with specific reference to the WDF.

The first MULINO-DSS prototype (μDSS^1) will incorporate the DPSIR approach as the reference framework for decision making. In this initial version multi-sectoral indicators describing Driving forces, Pressures, and the State of environmental resources will have a link with external spatial data such as results from complex hydrologic models.

The second MULINO-DSS prototype (μDSS^2) will incorporate an active interface with external complex hydrologic models within the system, and may also incorporate simple hydrologic models (with components for unsaturated/vertical & saturated/lateral flow, runoff, channel flow, and nitrate transport).

The third MULINO-DSS prototype (μDSS^3) will incorporate more hydrologic models/algorithms within the system.

The abandonment of older prototypes is not envisaged because they are all considered to be potentially useful for different applicative contexts. These multiple applications will be specifically valuable for acquiring insights that will guide the choice of hydrological models and the way in which they can be integrated into the system. Moreover, they will be the focus for research efforts targeted to investigate the relationship between modelling and decision making. Hydrological models should be employed in particular to describe the transition from Pressure to State and to simulate the expected results of proposed Responses.

A selection of models being considered by the research team offer a choice of foci from rainfall runoff, river flows, water that feeds into aquifers, and water management in lakes. These models differ in their approaches to spatial variability, their consideration of the time step of hydrological processes, and their ability to represent chemical flows. In this way, the results can be highly responsive to DSS users' needs and flexible to a chosen decisional context (μDSS^1 and μDSS^2). The integration of different models and functions envisaged in the first two prototypes will introduce some specific problems such as the combination of results with different spatial and temporal scales, which may be more easily solved in the development of the last version (μDSS^3), which, on the other hand, will provide less flexibility for applications in broader territorial and decisional contexts.

5. MULTI-CRITERIA ANALYSIS

In order to evaluate the alternative responses being explored by the DSS user in any particular decision context, a multi-criteria analysis (MCA) will be the final phase before arriving at a response selection., The DSS user may begin this evaluation process only after constructing an analysis matrix (see fig. 3) through choices made while exploring the D – P – S part of the cycle. Beginning with the Driving forces, the DSS user explores the system selecting indicators relative to the decision context, describing R^0, or the "no response situation". Following runs are used to describe the situation resulting from hypothesised responses, thus creating an analysis matrix consisting of rows and columns. The series of alternative situations (rows), resulting from the DSS user hypothesising various possible responses with the help of the framework describe changes in specific parameters (criteria), and the criteria themselves (columns), are selected for their relevance to the problem or the objectives that condition the decision. By studying the likely results of proposed Responses in this way, each alternative consists of a number of parameters which may describe variations in Driving forces, Pressures or the State of water resources.

The preferences about the consequences of alternatives are mapped by a value function which is applied to each parameter individually. In this process the DSS user must be supported by value functions that express preferences in reference to decision making objectives and limitations. The end product is called the evaluation matrix in which parameter values show their significance in a particular decision context.

The final step to the MCA involves applying a decision rule to the mapped preferences in order to aggregate the values and attribute one single value to each alternative thereby deriving the basis for selecting one response over the others [Hwang, 1981].

It should be noted that the DSS user will have the liberty to begin exploring the decision problem by commencing with what is considered to be the Impact and constructing the chain in the I – S – P – D direction. The result of this preliminary exploration can be a detailed description of the Impact (Figure 3), especially useful in the case where the stimulus for taking a decision is the need to mitigate negative impacts resulting from current water use patterns such as an insufficient water supply impacting on the possibility to irrigate the desired land surface.

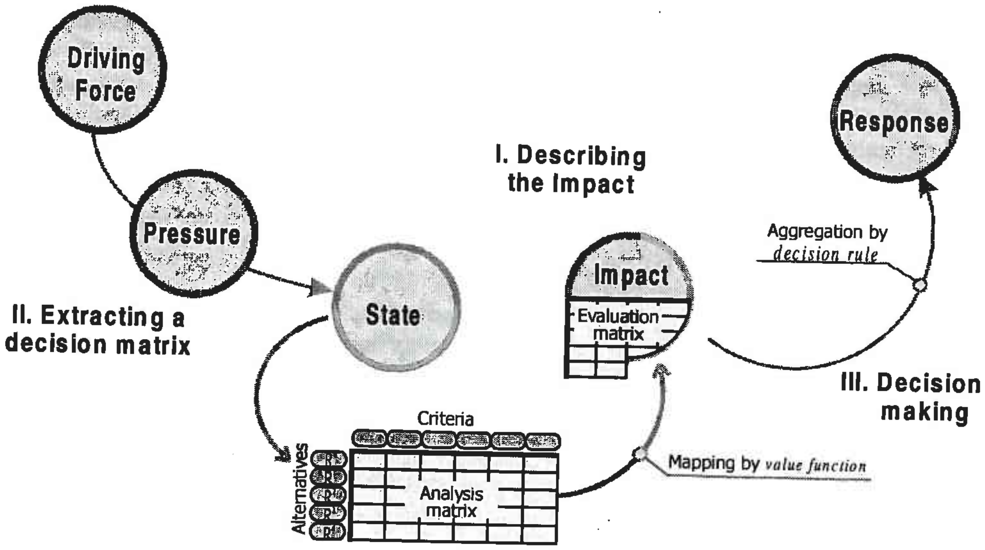

Figure 3. Multi-criteria- Analysis for the definition of Responses.

6. APPLYING DSS ON THE GROUND

Mulino's study sites are found in, Romania, Italy, Portugal, the United Kingdom and Belgium. They range in size from 300km^2 to 2500km^2. Variations in hill slope, in rainfall, the presence of groundwater, and in current water use practices render each case study unique. Local legislation and local language add to the individuality of these situations.

The decision contexts have been defined in co-operation with representatives from water authorities who are engaged in solving water management problems resulting in an interesting sample of issues that condition the decision making process. In Italy the objective is to increase the quality of waters that flow into the Venice lagoon; in Portugal the catchment has trans-national boundaries with Spain; in Belgium nitrate concentrations in ground waters exceed drinking water norms; Romania is seeking to become part of the European Union and compliance with the WFD is seen to be important for their negotiation platform; and in the UK water abstraction for public water supply and agriculture are major pressures.

7. CONCLUSIONS

The project presented in this paper is in the initial phase in which theoretical backgrounds and assumptions must be turned into concrete designs of software modules (hydrologic modelling, scenario development, multicriteria analysis, etc.), to be integrated into a unique DSS tool.

Preliminary discussions and feasibility analyses have substantially confirmed the basic ideas developed during the elaboration of the project proposal, but strong efforts will be required to transform them into operational routines. The adoption of the DPSIR approach, which was envisaged from the beginning, will require the development of new theory and applied knowledge to allow the practical implementation of this framework. Despite its numerous presentations and citations in the current environmental and socio-economic literature, few concrete applications can be found, especially if one focuses on the water management sector and, even more, if one looks for its application in a geographical context.

A challenging field of research is the integration of hydrologic and other models in the DPSIR framework and their use in real world decisional contexts. One of the most difficult tasks envisaged so far, will be the development of the interface between intrinsically complex, distributed and mechanistic hydrologic models, and the lumped, empirical and often implicit decisional rules, traditionally adopted by water management authorities. For this reason three different versions of the tool have been designed. The identification of their real application potentials for the MULINO case studies will be, in itself, a research task for the project.

Trade offs are envisaged between potentials for practical implementation and the software's complexity. These trade offs will depend primarily on the modelling components, as in many other previous projects in the DSS discipline. MULINO aims at contributing to this field particularly through the specific emphasis placed on the involvement of end users from the beginning of the project.

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